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Comparison of ductile fracture properties of aluminum castings: Sand mold vs. metal mold

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Abstract

This paper compares mechanical properties of two types of cast aluminum components made in sand molds and cast iron molds, respectively. For each type of the castings, a total of 12 fracture tests are performed under a wide range of stress states including 6 tensile tests on notched and unnotched round bars and 6 biaxial loading tests on butterfly specimens. Using a combined experimental–numerical approach, the plasticity and fracture properties of the components are characterized in terms of the true stress–strain curve and the ductile fracture locus. It is found that the sand-molding component is of higher yield resistance and lower ductility than the metal-molding one. Meanwhile, the fractographic study reveals that there exist two competing failure mechanisms: the internal necking of the matrix at high positive stress triaxialities and void sheeting due to shear at negative stress triaxialities. The transition of the failure modes occurs in the intermediate range. This suggests that a ductile fracture locus formulated in the space of the stress triaxiality and the effective fracture strain consist of three branches rather than a monotonic curve.

Keywords: Failure mechanism; Ductile fracture criterion; True stress–strain curve; Cast aluminum alloy; Sand mold; Metal mold

1. Introduction

Sand and metal are two types of mold media commonly used in casting manufacturing processes. Because of superior heat dissipation ability, metal molds are able to rapidly solidify cast alloys and thus to refine dendrite cells. Cast components made in metal molds usually exhibit higher ductility than in sand molds.

The improvement of mechanical properties of aluminum castings by increasing solidification rates was reported in the literature. Cáceres et al. (1995) and Wang (2003) obtained a wide range of solidification rates in one single cast thick plate by attaching a large cast iron chill at one end. Tensile tests were performed on round bars prepared at different distances from the chill. It was shown that the specimen machined at the chilled end was of the largest elongation to fracture. Shabestari and Moemeni (2004) evaluated four different

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types of molds made of graphite, copper, cast iron, and sand, respectively. It appears that the graphite mold produces the casting of the highest ductility. In these studies, the material ductility was characterized through round bar tensile tests. A previous study reveals that cast aluminum components are of significantly higher resistance to fracture under shear than under tension (Mae et al., 2007). Hence, it would be interesting to study effects of solidification rates on fracture properties under compression and shear.

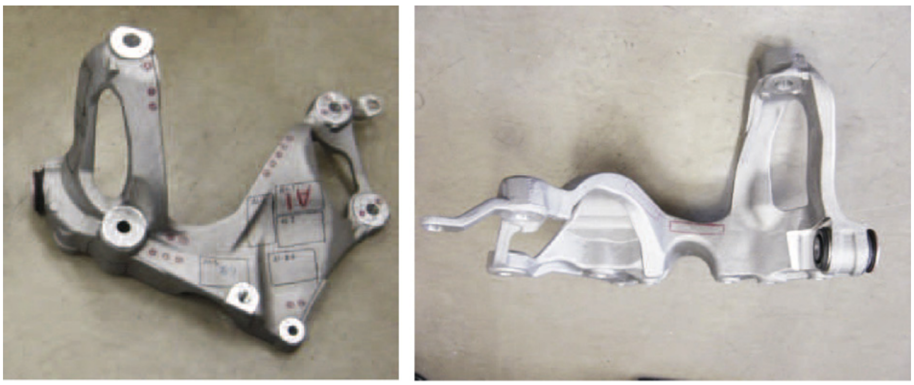
The ductility is closely related to material microstructure. Metallographic and fractographic analysis provides a deep insight into the failure mechanism of cast aluminum alloys. Powell (1994) found that aluminum castings tended to break by the intergranular fracture mode. By carefully reviewing the fracture surfaces of cast aluminum specimens, Leupp and Epprecht (1977) concluded that crack formation between grains was essentially of the ductile fracture type, though small plastic deformation always presented in tensile tests on cast aluminum components. Using scanning electron microscopes, Cáceres et al. (1995) and Wang (2003) discovered that the failure mechanism changed from the intergranular fracture mode to the transgranular one as the size of dendrite cells increased. Note, that those failure mechanisms were identified, all from tensile tests on round bars. In contrast to the tensile failure mechanism, the fracture mode of cast aluminum alloys under compression and shear is less understood. By observing polished fracture surfaces of high pressure die cast aluminum alloys, Mohr and Treitler (2008) suggested that shear instability would be a dominant failure mode for specimens under compression.

In this study, a systematic comparison of plasticity and fracture properties of cast aluminum components is made between sand molds and metal molds. A total of 24 fracture tests are conducted for the two types of castings including tensile tests on round bars and biaxial loading tests on butterfly specimens. The true stress–strain curve and the fracture locus are calibrated to characterize plasticity and ductility of the castings, and to differentiate effects of the mold media. Meanwhile, a fractographic examination on the specimens is performed to understand microscopic failure mechanisms under a wide range of stress states.

2. Specimen preparation and test procedures

All the specimens in the present paper were prepared from prototype components, see Fig. 1. The thin-walled casting is a part of an automotive chassis system. Since solidification rates vary with the geometrical dimensions and shape of castings, it is of practical interest to use a real product rather than a specifically cast block. The cast aluminum components were made of the A356 aluminum alloy in sand and cast iron molds under gravity pressure, respectively. By contrast, low pressure die casting was used in a previous study (Mae et al., 2007). Table 1 lists the chemical composition of the A356 aluminum alloy. The T6 heat treatment was applied, which is believed to improve the ductility of the castings.

Depending on stress states and loading histories, a material may display different levels of ductility. An early study indicates that cast aluminum components under compression are able to undergo significant plastic deformation without failure while under tension the effective plastic strain to fracture is only a few percentages (Mae



(a) Isometric view (b) Side view

Fig. 1. A cast aluminum component studied in this research. The rectangles and the small circles marked on the exterior surface represent, respectively, the cutting locations of the specimens for the fracture test and of the cylinders for the metallographic study.